

[54] VARIABLE INDUCTIVE REACTOR

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[51] Int. Cl. H01f 21/06

[58] Field of Search 336/130, 132, 134; 324/54

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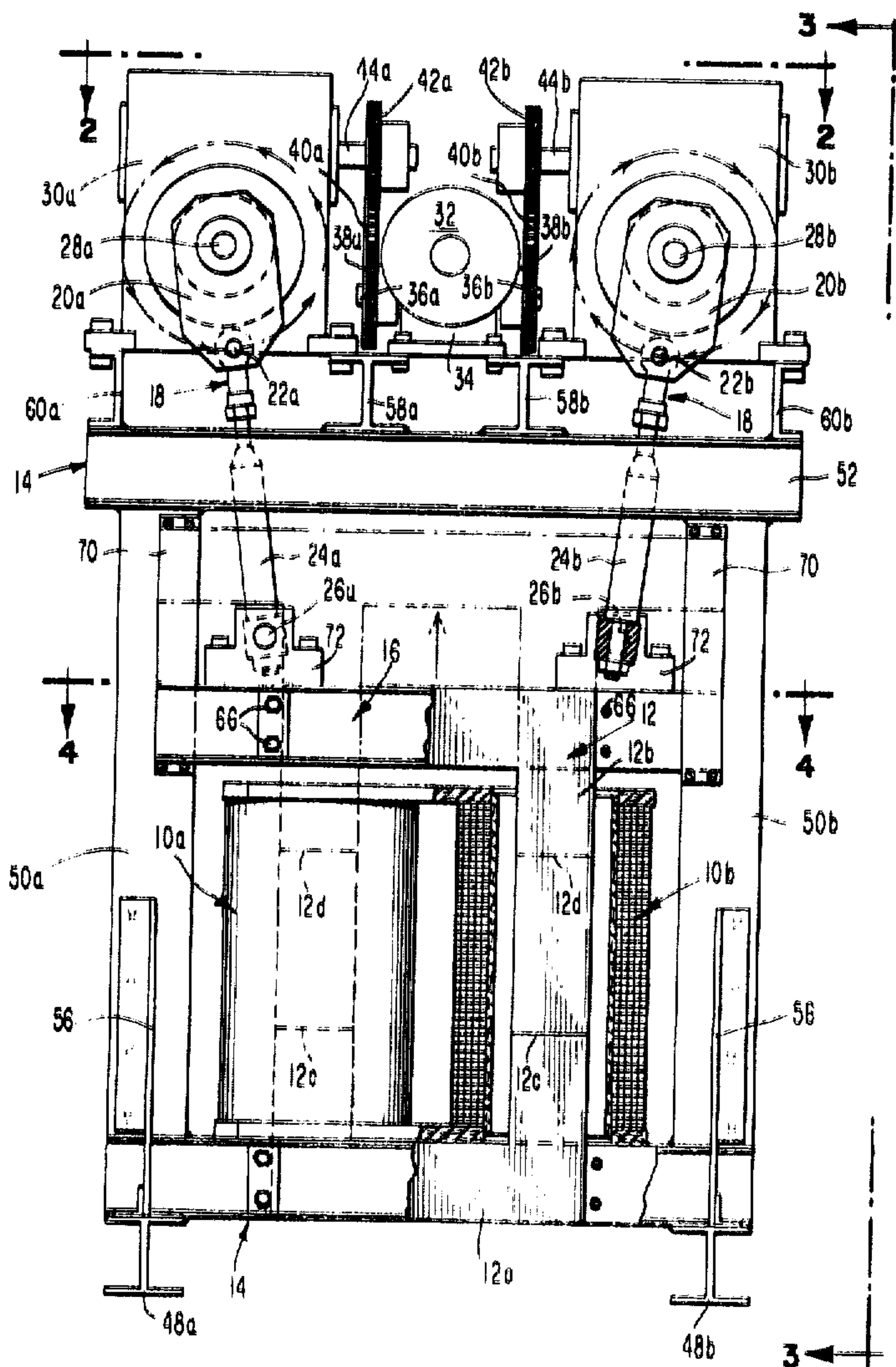
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Primary Examiner—Thomas J. Kozma
Attorney, Agent, or Firm—Dorfman, Herrell and Skillman

[57] ABSTRACT

Opposed U-shaped magnetic cores together providing a magnetic circuit are arranged in a vertical plane with cooperating legs of the U-shaped cores extending vertically. The lower U-shaped core is fixed to the frame to which inductive windings surrounding the vertical legs are also mounted. The upper core is supported on a movable member slidable up and down in a vertical directional along a track on the frame in order to open and close the air gaps between the U-shaped core members within the winding surrounding the vertical legs. Actuator means on the frame connects the frame and the movable support means and consists of a driven crank and an articulated linkage. The actuators are preferably employed with a common drive means to drive the cranks synchronously through a symmetrical drive structure.

9 Claims, 14 Drawing Figures



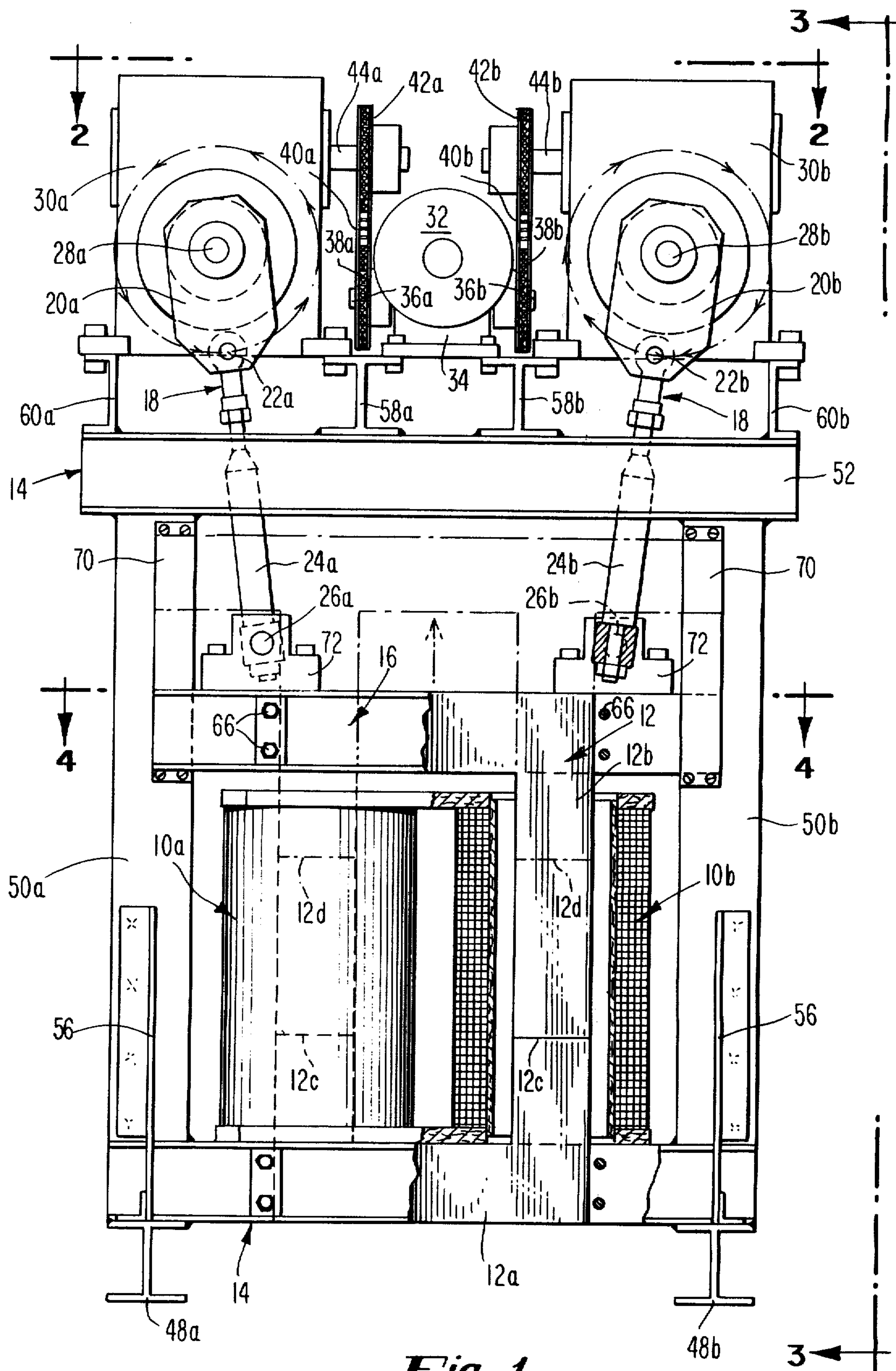


Fig. 1

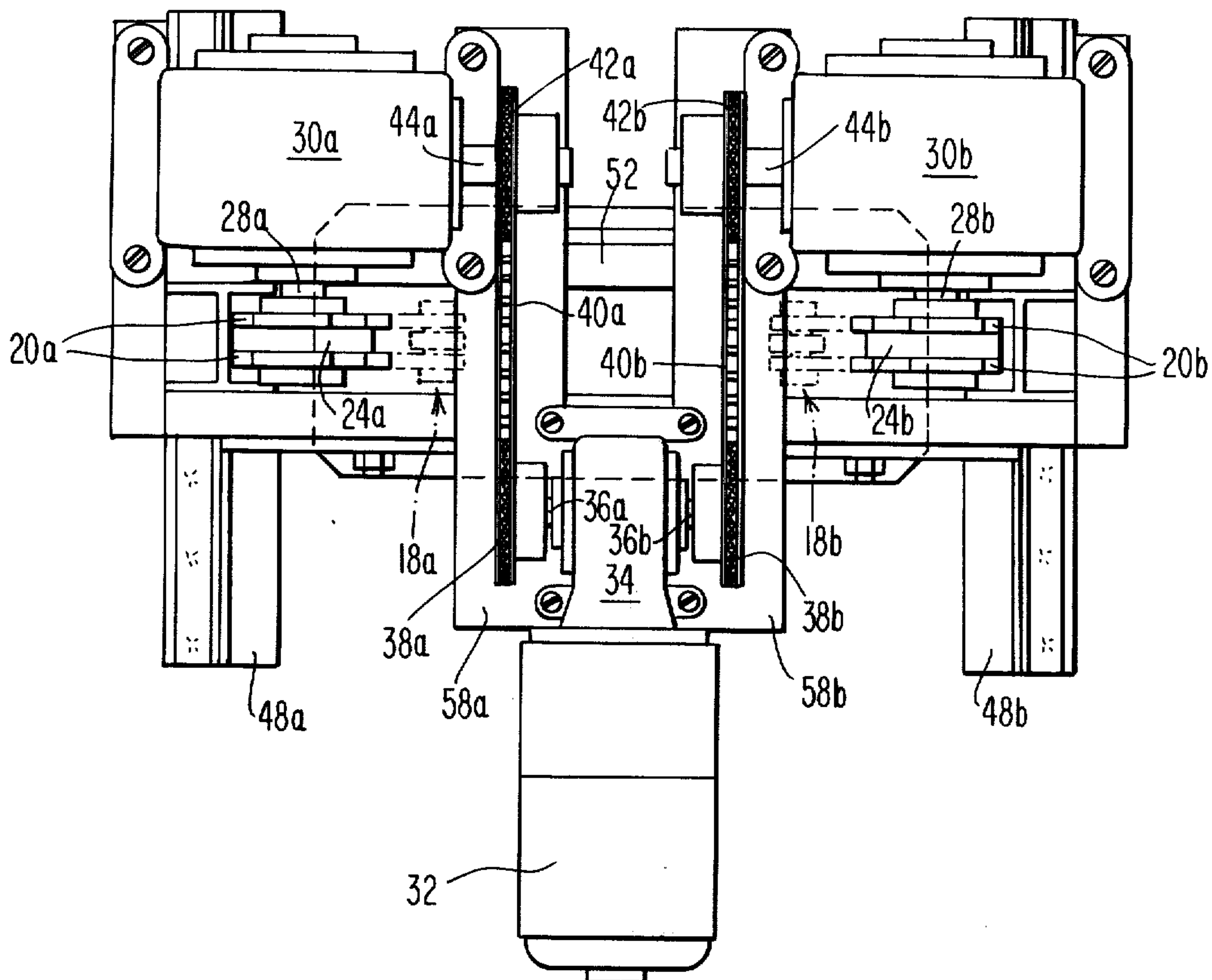


Fig. 2

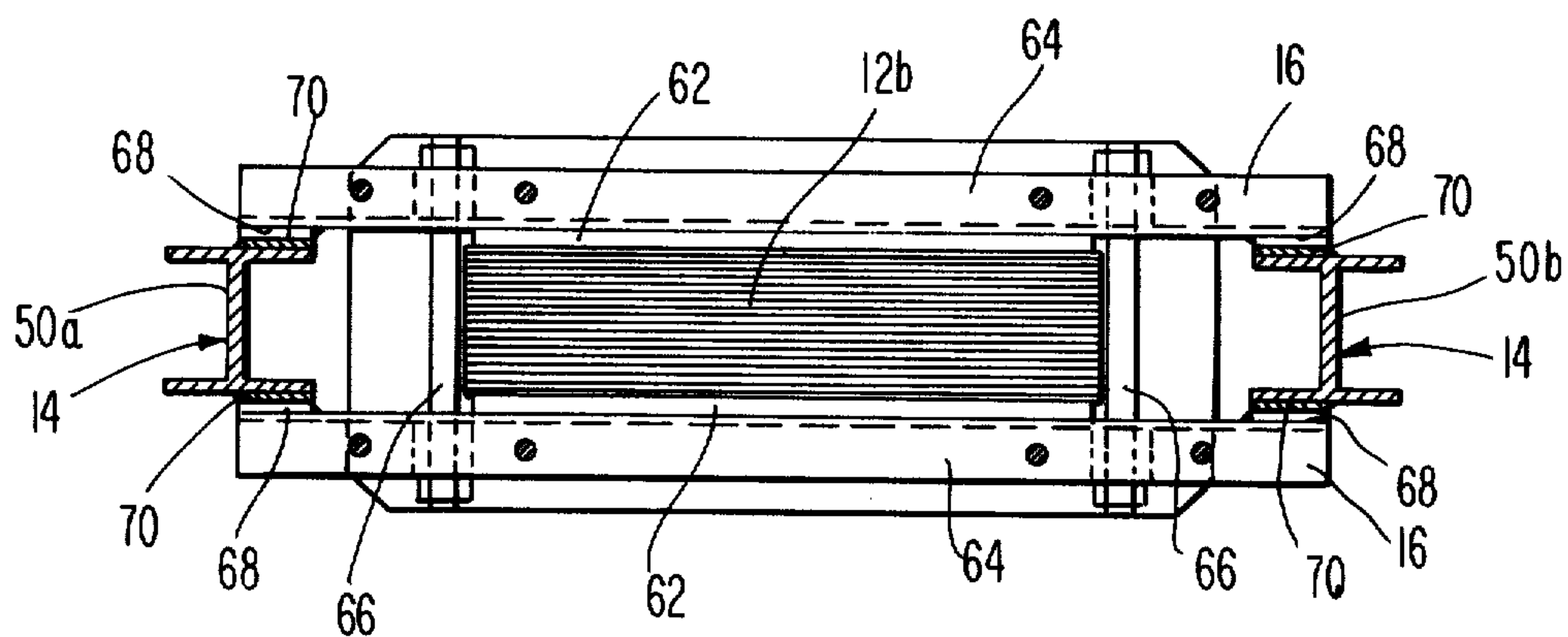


Fig. 4

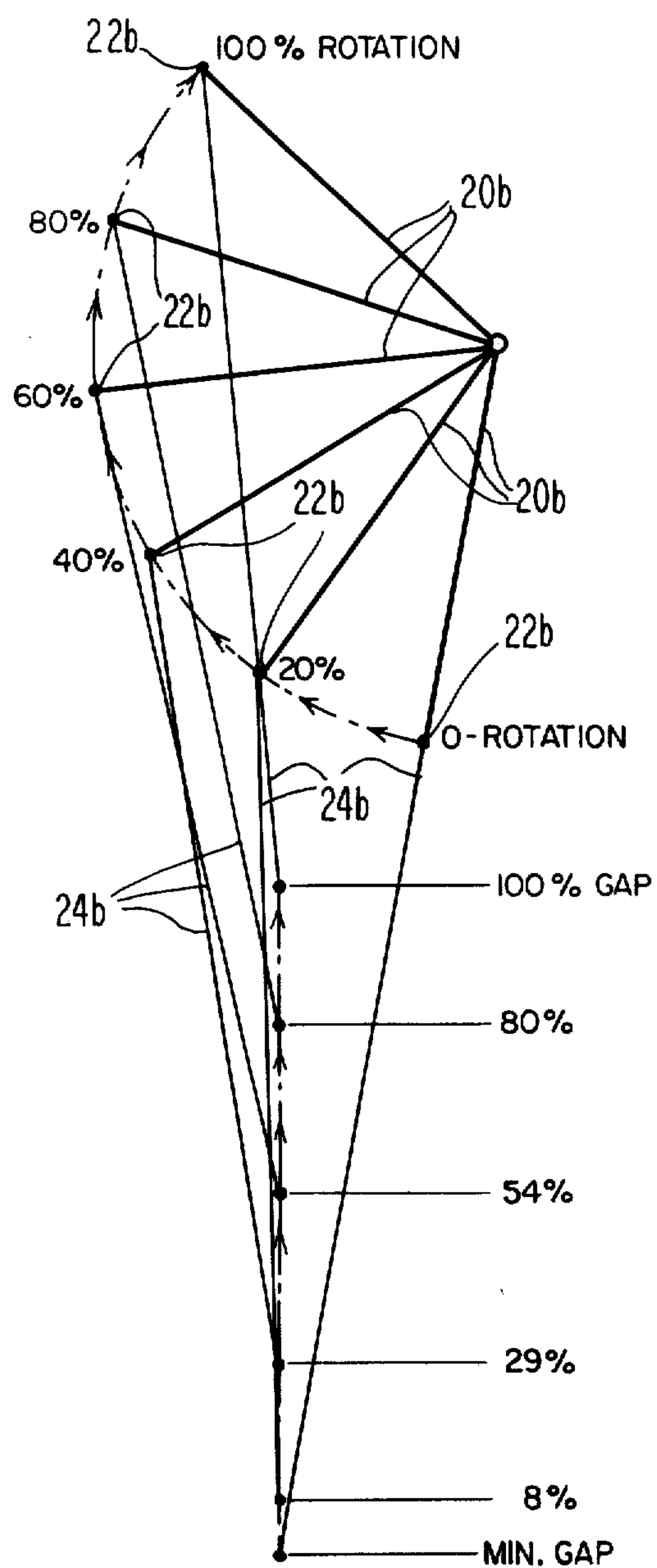


Fig. 11

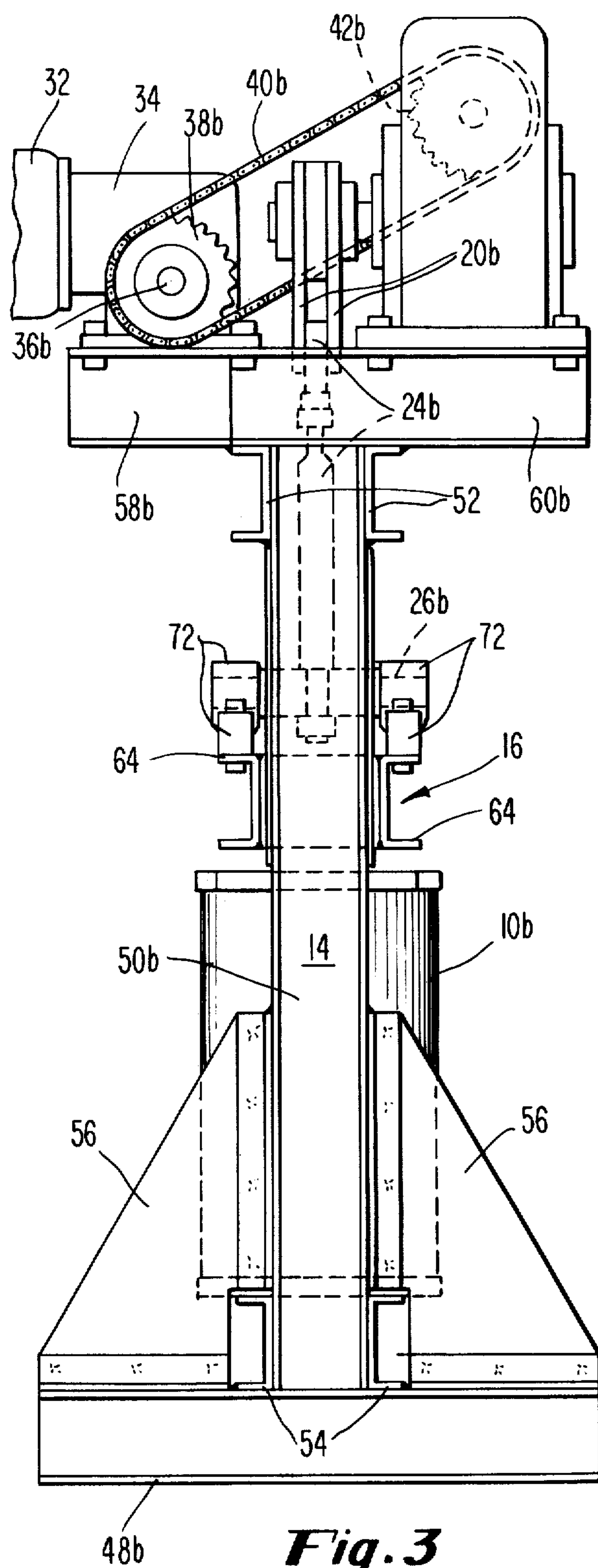


Fig. 3

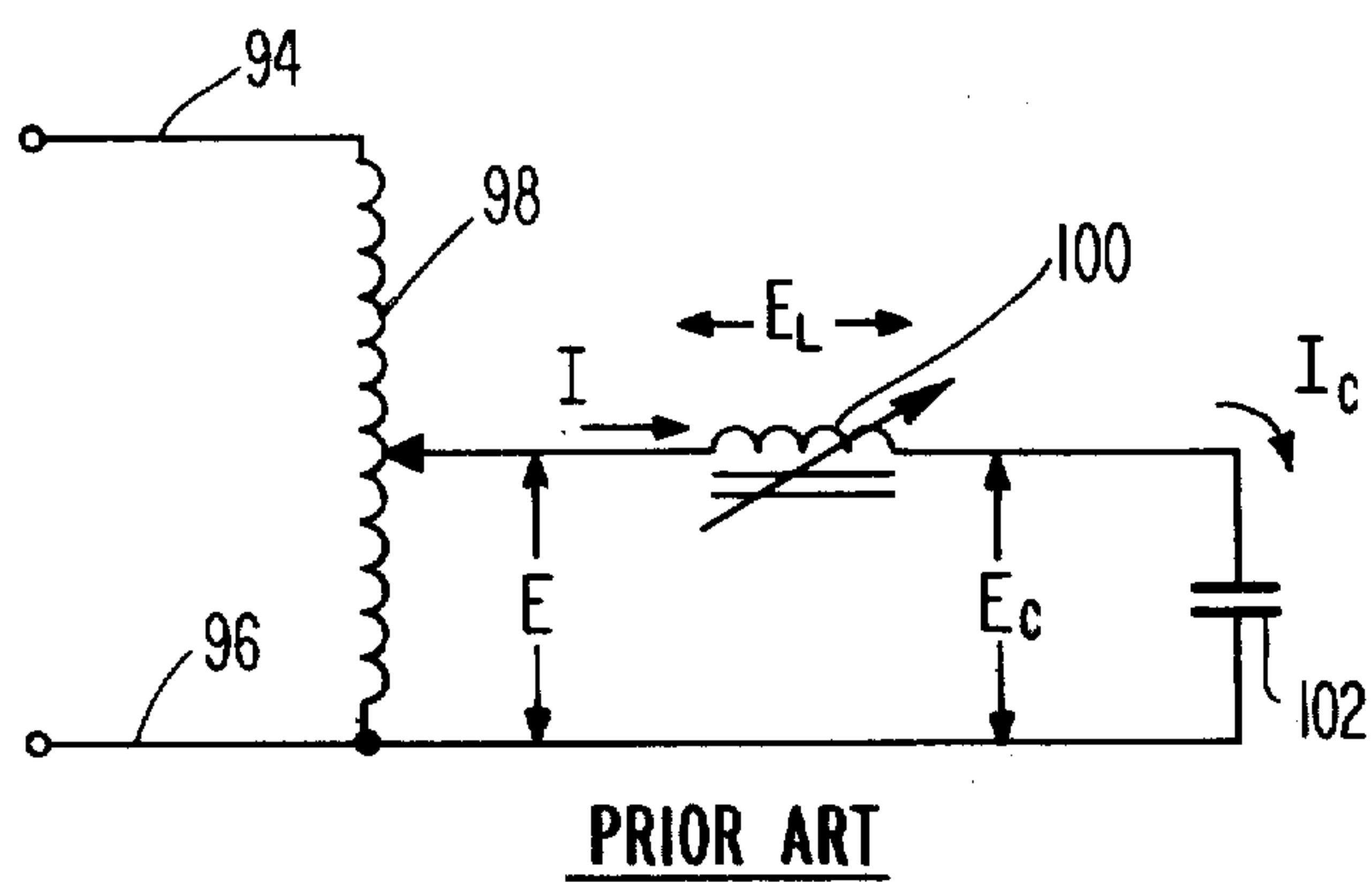
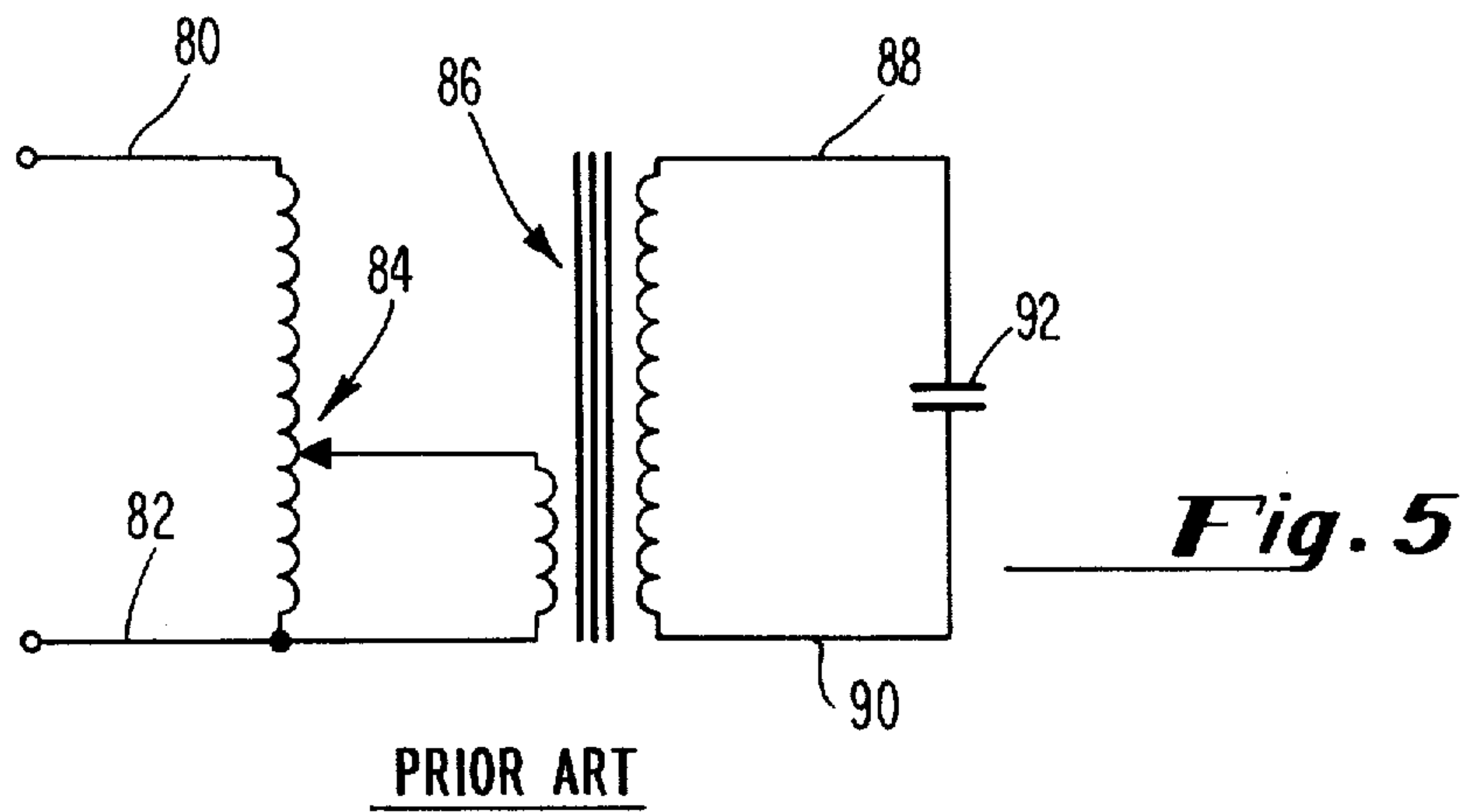


Fig. 6a

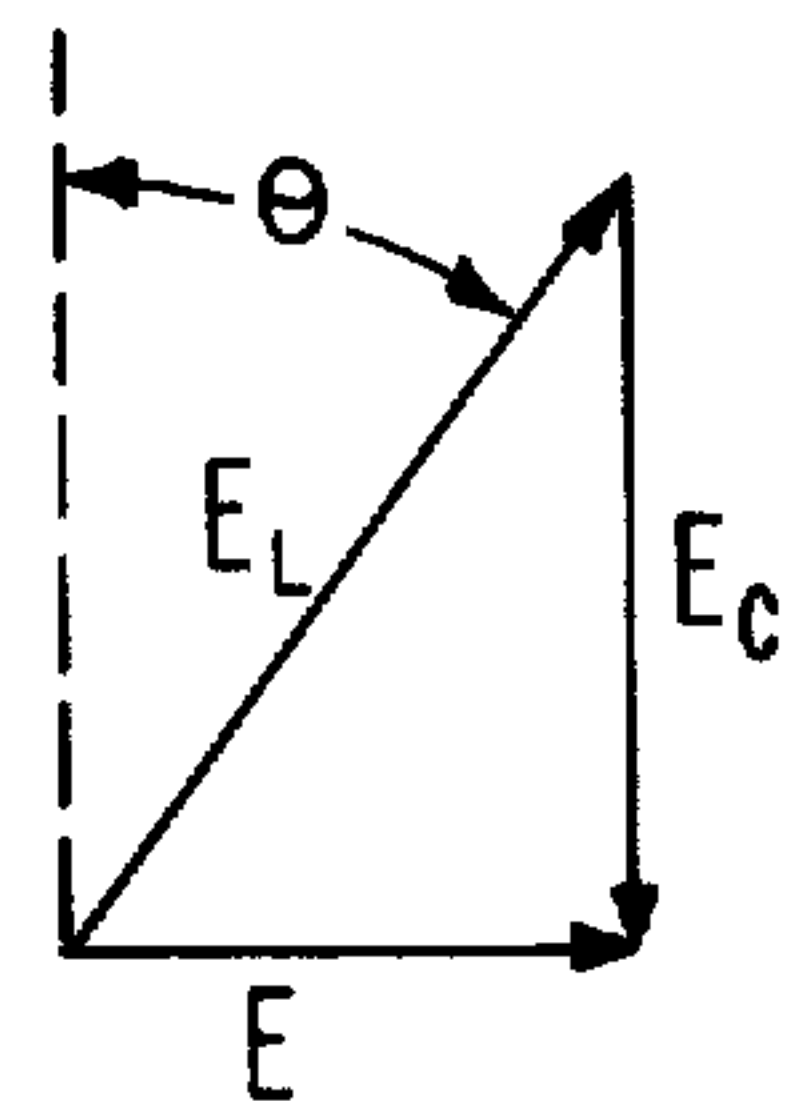


Fig. 6b

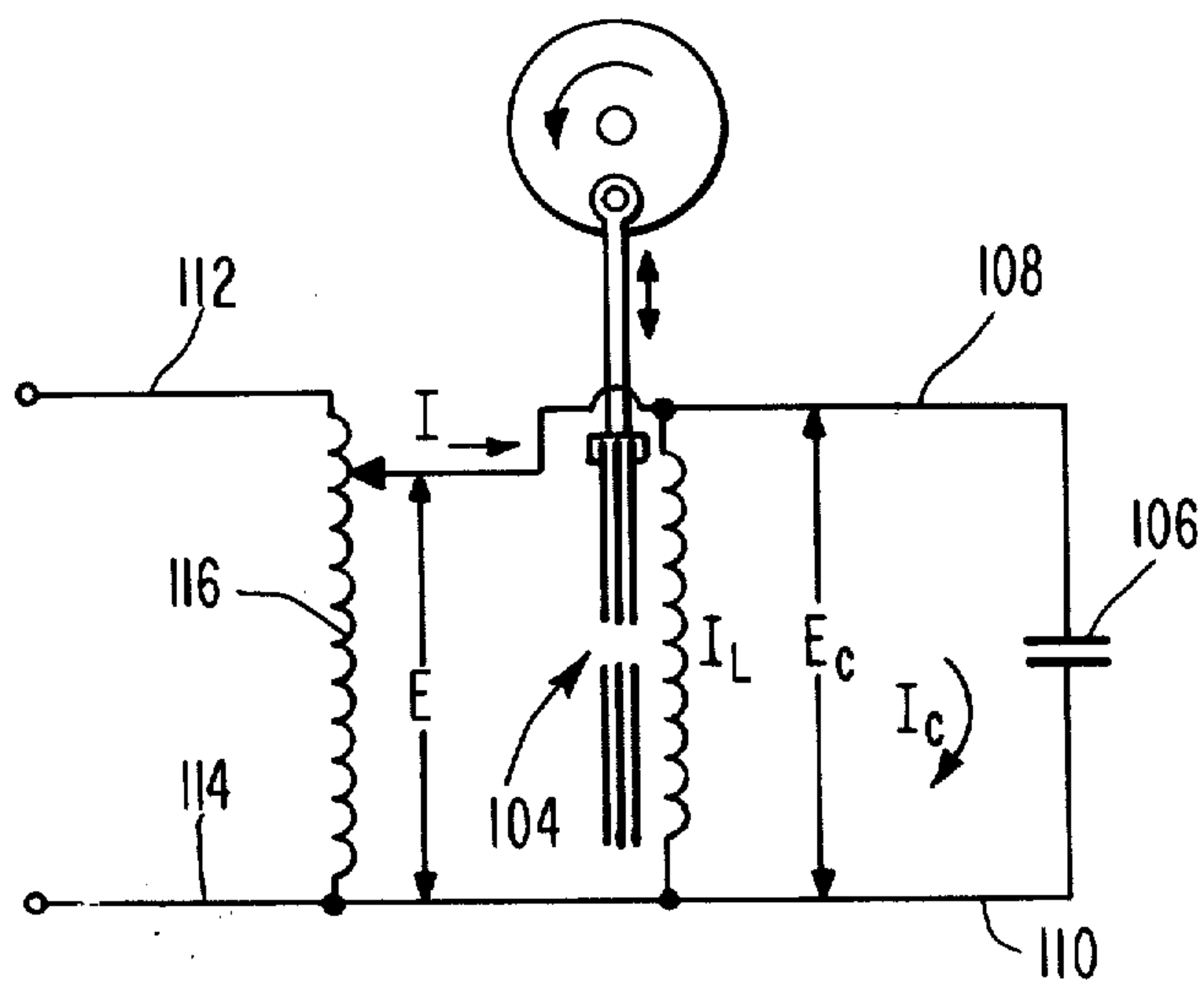


Fig. 7a

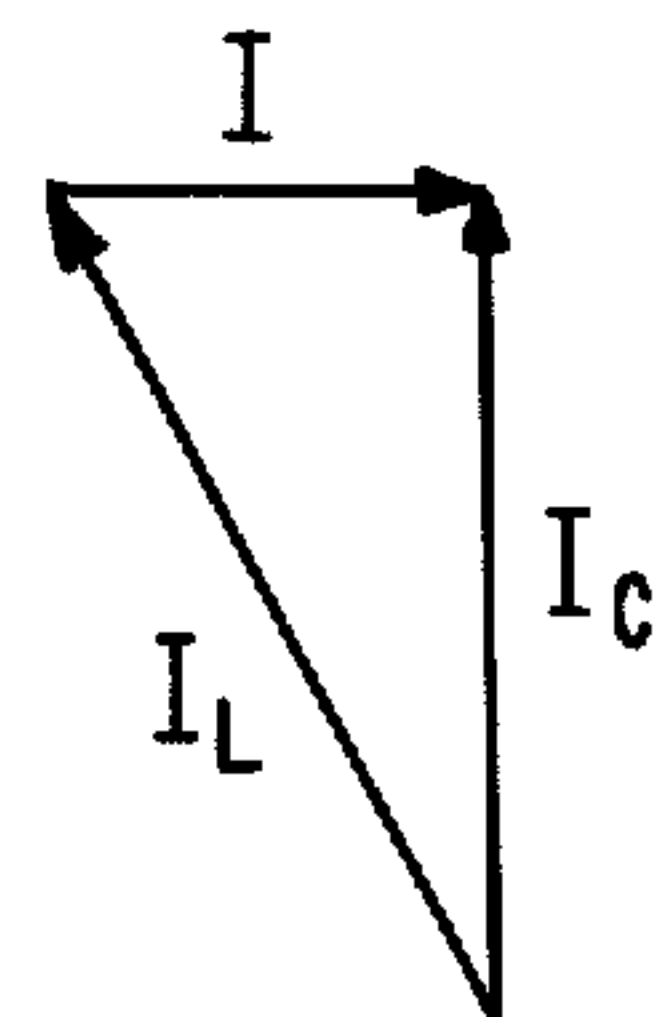


Fig. 7b

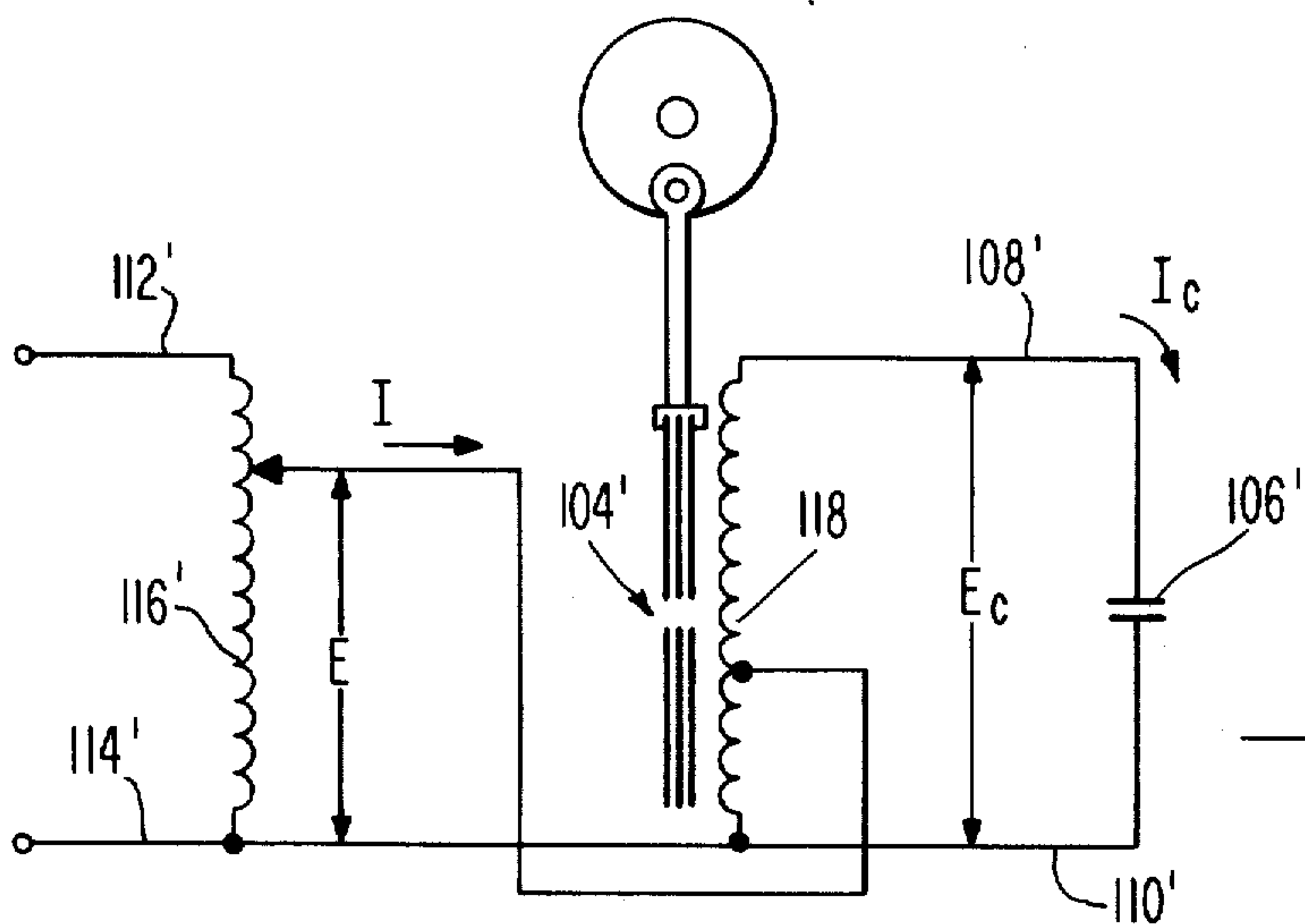


Fig. 8

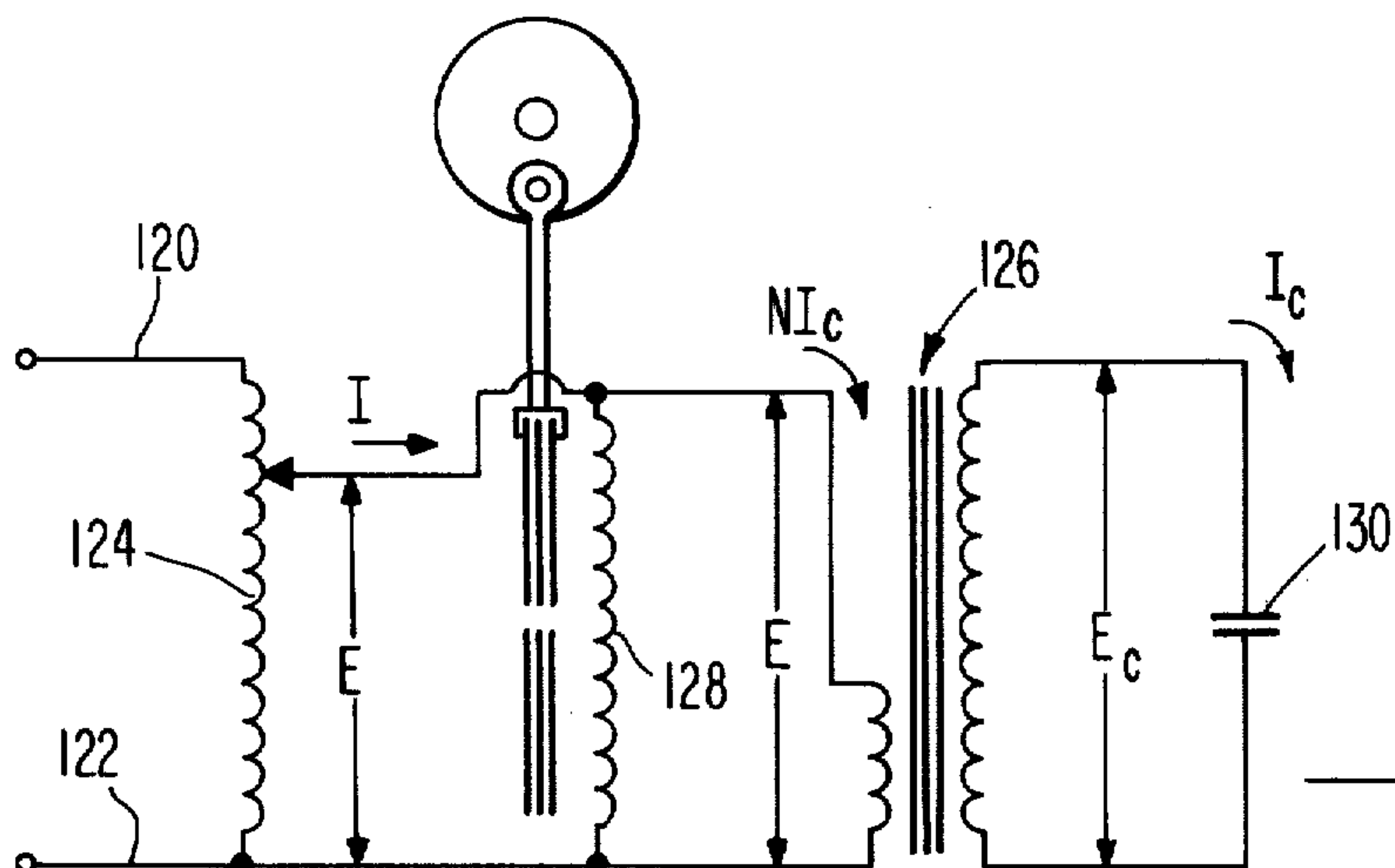


Fig. 9

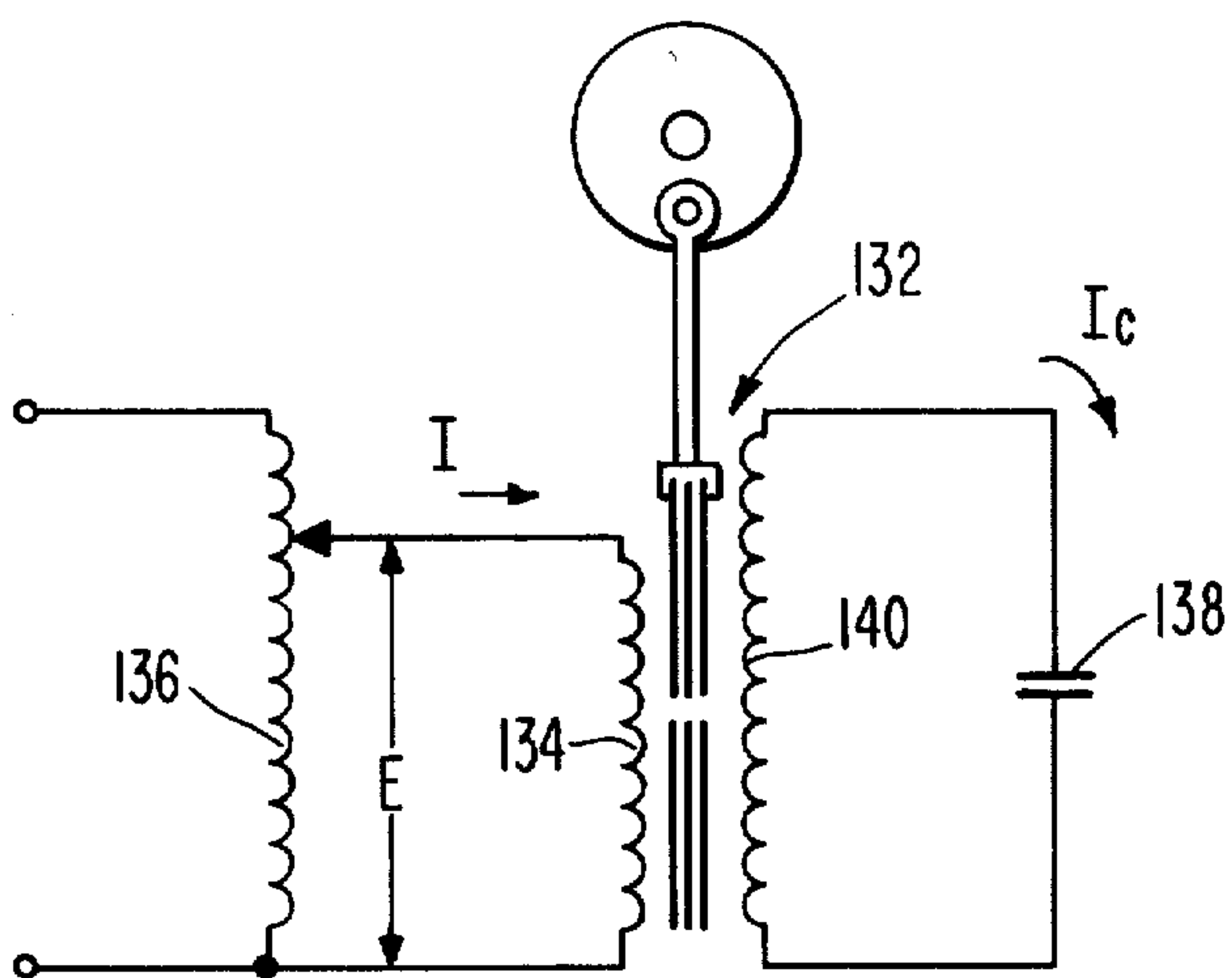
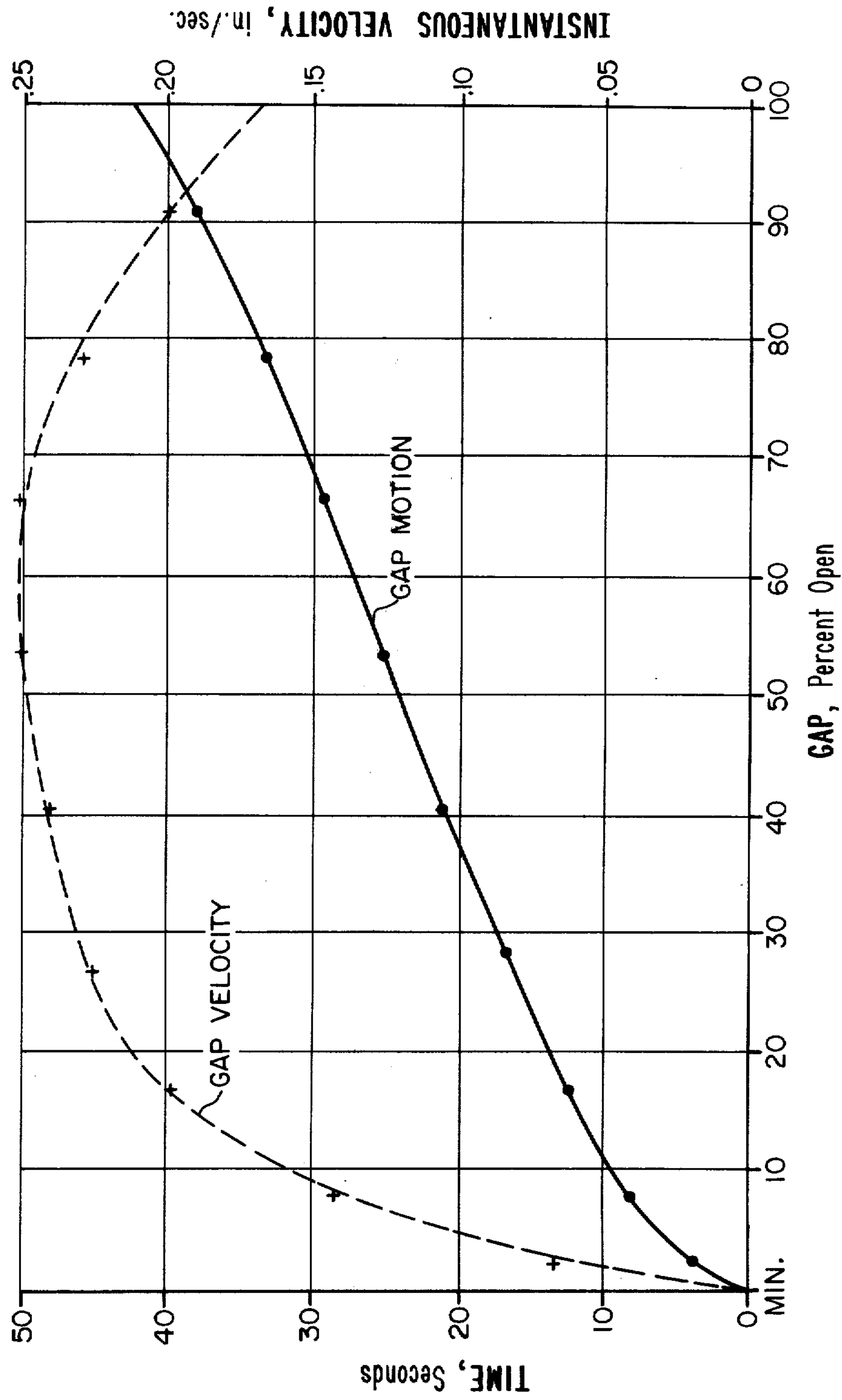


Fig. 10

Fig. 12



VARIABLE INDUCTIVE REACTOR

The present invention relates to a variable inductive reactor and more specifically relates to an inductive reactor having movable core portions such that the movement allows variation of air gaps in the magnetic circuit. Novel actuator means provides a simple reliable repeatable means of moving the separable core members apart and back together.

In the prior art, inductive reactors having a magnetic core in which an air gap can be varied upon demand have been used for various types of test applications. Such devices for power applications are subject to extremely high magnetic forces and have required massive cores and sturdy frames to support them as well as strong mechanisms to pull the magnetic cores apart when a air gap must be changed. An example of the problem and one solution of a general type using screw elements to drive the cores apart is shown in U.S. Pat. Nos. 3,609,614 and 3,703,692. Drives of this type have low efficiency and usually require a relatively long time to make the gap change. By contrast the present invention provides a means which will efficiently operate to vary the gap when it is needed and which permits closing of the gap using magnetic and gravitational force.

More specifically, the present invention relates to a variable inductive reactor having a pair of laminated iron core members, each having at least a portion of generally U-shape, the legs of which are opposed and together define a magnetic circuit, said core means being separable to provide air gaps in the magnetic circuit between opposed legs. The frame supports one of said core members and the coil means is supported on the frame in position to surround at least one said opposed legs at the air gap, thereby to provide the variable inductive reactor. Movable support means is provided for the other said core member and the movable support means has a slidable cooperative relationship with the frame whereby movement is restricted to a predetermined fixed and repetitive path producing an opening of the air gap in one direction and a closing of the air gap in the other direction of movement. Actuator means acts between the frame and the support means to produce such movement and includes a pair of symmetrically arranged crank elements connected to articulated linkages. Drive means is provided to move the cranks in synchronism between predetermined positions providing preselected alternative core positions.

Preferably, in the variable inductive reactor, the frame supports one of the cores with its legs extending generally vertically upwardly and a pair of coils are provided, which together constitute the coil means, one of the coils surrounding each of the legs. The movable support means is preferably slidable along a linear vertical path relative to the frame and the cranks turn in opposite directions in an essentially common plane about parallel axes. Preferably, also, the drive means is a common motor means operating through similar coupling through each crank.

For a better understanding of the present invention, reference is made to the accompanying drawings, in which:

FIG. 1 is a front elevational view of a preferred embodiment of the variable inductive reactor or transformer of the present invention partially in section and showing some of the construction in phantom;

FIG. 2 is a plan view from above taken along line 2—2 of FIG. 1;

FIG. 3 is a side elevational view taken along line 3—3 of FIG. 1;

FIG. 4 is a sectional view taken along line 4—4 of FIG. 1;

FIG. 5 is a schematic diagram showing schematically a prior art a.c. insulation test circuit;

FIG. 6a represents a modified prior art test circuit;

FIG. 6b is a phasor diagram useful in interpreting results of the use of the circuit of FIG. 6a;

FIG. 7a is a schematic a.c. insulation test circuit arrangement employing the present invention;

FIG. 7b is a current diagram representing operation of the circuit of FIG. 7a;

FIG. 8 is a diagram of a modified circuit for another type of a.c. insulation test system in accordance with the present invention.

FIG. 9 is a diagram of a further modified circuit;

FIG. 10 is a diagram of another modified circuit;

FIG. 11 is a diagrammatic view showing various stages in the movement of the actuator means of the structure of FIGS. 1—4; and

FIG. 12 is a graphical representation of gap motion and gap velocity in a structure made in accordance with FIGS. 1—4 and 11.

Referring first to the structure shown in FIGS. 1—4, the device illustrated is a preferred embodiment of a variable inductive reactor in accordance with the present invention. In order to better visualize the structure, certain conventional structural details such as a means of fastening parts of the frame together or the frame and other structure to other pieces have been omitted. For the sake of clarity, dashed lines have been used to show location of hidden structure.

The variable inductive reactor is basically an electrical coil or winding, sometimes referred to as coil means and in this case consisting of two coils 10a and 10b, surrounding a magnetic core generally designated 12 and consisting of a pair of laminated core members 12a and 12b of general U-shape. Coil means as used herein may broadly include a single or multiple windings surrounding one or both legs of the cores. The windings around the respective legs may, for example, be connected in series or in parallel or to provide windings of a transformer. The coils 10a and 10b and the core member 12a are supported on a frame generally designated 14. The other core member 12b is fixed to and movable with movable support means 16. Support means 16 has a slidable cooperative relationship with the frame whereby movement is restricted to predetermined fixed and repetitive path. The movable support means moves from the position shown in full lines to a position shown in dot-and-dash lines. Movement into the position shown in dot-and-dash lines by the movable support means draws the iron core member 12b to open an air gap which is represented by the space between a plane 12c between the faces of the opposed legs of the U-core members and a position, 12d, shown in dot-and-dash lines which represents the bottom of the legs of the movable core member 12b in its upper position. It will be observed that the core members together form a hollow rectangle with square corners, in the embodiment illustrated. While each of the core members is of similar U-shaped form, the lower fixed core member mounted on the frame 14 with the legs of the U extending vertically upward has shorter legs than the U of the

movable core 12*b*. The movable core 12*b* is oriented so that its longer legs meet squarely with the legs of core 12*a* normally in closed position at plane 12*c* so that a minimum air gap exists. The design is such that even when the air gap is at its maximum opening, the bottom of movable core 12*b* has the bottoms 12*d* of its legs still within the coils 10*a* and 10*b* so that the gap is entirely within the coil structure in the preferred embodiment.

A pair of similar actuator members, generally designated 18, consists of a pair of symmetrically arranged crank elements 20*a* and 20*b* pivotally connected by parallel horizontal pins 22*a* and 22*b* to articulated linkages 24*a* and 24*b*. The linkages 24*a* and 24*b* are pivotally connected by pins 26*a* and 26*b* to the movable support means 16. The cranks 20*a* and 20*b* are supported on and driven by horizontal drive shafts 28*a* and 28*b* which are rotatably supported in gear boxes 30*a* and 30*b* and, in turn, mounted on the support frame. It will be observed that the pin connections 22*a* and 22*b* and 26*a* and 26*b* are all parallel to each other and parallel to the drive shafts 28*a* and 28*b* and generally perpendicular to the planes in which the core structure lies.

Drive is supplied through suitable motor means 32 supported on the frame. In the embodiment shown, the motor is located between the two cranks with its drive shaft parallel to the shafts 28*a* and 28*b* of the cranks and the aforementioned pins and is provided with a dual takeoff, as best seen in FIG. 2, through gear box 34 which provides coaxial shafts 36*a* and 36*b* extending in opposite directions and supporting respectively sprocket wheels 38*a* and 38*b*. These sprocket wheels turn drive chains 40*a* and 40*b* which engage sprocket wheels 42*a* and 42*b* supported on shafts 44*a* and 44*b* of gear boxes 30*a* and 30*b*, shafts 44*a* and 44*b* being parallel to shafts 36*a* and 36*b*.

The frame which supports the structure in this embodiment is typically constructed of suitable structural steel shapes such as I-beams, channels, and the like. A pair of horizontal I-beams 48*a* and 48*b* at opposite ends of the width of the machine extend a sufficient distance, fore and aft of the core members to give stability to the frame. The feet in turn support a hollow square frame consisting of a pair of vertical I-beams 50*a* and 50*b* fixed together at their top edges by similar horizontally arranged channels arranged back to back but spaced apart the width of the I-beams members 52 and at the bottom edges by similarly arranged horizontally channel members 54. Four generally triangular flanged braces 56 extend between each of the vertical frame members 50*a* and 50*b* and the fore and aft portions of their respective feet 48*a* and 48*b*. A pair of closely spaced parallel I-beams 58*a* and 58*b* are supported horizontally, perpendicular to the channels 52 and, in turn, provide a platform for support of the housing of motor gear box 34 to which the housing of motor 32 is attached and thereby supported. At the outer edges of the channels 52, and parallel to the I-beams 58*a* and 58*b*, are a pair of channels 60*a* and 60*b* set on one flange so that the other flange is at the same height above the channels 52 to complete the platform for and support the other edges of the gear boxes 30*a* and 30*b*. The channel 58*a* and 58*b* respectively provide the support for the other edge of said gear boxes.

The movable support means 16 preferably consists of channel members 62 arranged back-to-back but spaced apart the width of the laminated core 12*b*, as best seen in FIG. 4. The structure is held with proper spacing by

the use of spacer members 62 on the opposite sides of the core structure between the laminae of the core and the channel members 64. The channel members are arranged back-to-back and held together with suitable bolts or clamping members 66 and whatever auxiliary structure is necessary to hold the core in proper position. The channel members 64 bracket the I-beams 50*a* and 50*b* at their opposite ends and are provided with bearing slide surfaces 68 which run on tracks 70 of suitable low friction material fixed to the upright I-beams 50*a* and 50*b* of the frame. The slide arrangement provides a suitable track for repetitive movement of the upper core member from the position shown in full lines in FIG. 1 to the position shown in dashed lines in that figure and then back to closed position.

Suitable coupling members 72 for connecting the channels 64 supporting the movable core portion to the linkages 24*a* and 24*b* are bolted to the upper flanges of the channels. The linkages themselves may be provided with length adjustment elements which permit by minor adjustment compensation for tolerances and small structural inaccuracies encountered in manufacturing or in use of the equipment.

In order to better appreciate an important function of the inductive reactor of the present invention some background of its use in a system of a.c. testing of insulators is helpful. Furthermore, it seems desirable to contrast the prior art in this field with application of the present invention.

The present trend of electrical distribution and transmission is toward the increasingly wide use of subterranean cable. In addition, the voltages at which distribution and transmission are accomplished continues to increase. Since these cables consist of one or more conductors surrounded by a dielectric medium, the whole encased in a conductive shield or "ground" conductor, it will be seen that a cable is actually an example of that electrical parameter known as capacitance and is capable of storing large amounts of electrostatic energy. Subterranean distribution places severe demands upon the reliability of the installed cable and requires careful testing at voltages above those at which the cable is to be operated. The trend toward increasing operating voltages in electrical generation also produces similar problems with generator insulation.

Historically, a.c. insulation systems have been tested by the use of a variable voltage device and a step-up transformer as illustrated in the schematic circuit diagram FIG. 5. In this circuit alternating current energy is introduced from the mains, 80 and 82, into a variable voltage device 84, such as a variable autotransformer or induction regulator. The output of the variable voltage device is then introduced into the primary winding of a fixed-ratio step-up transformer 86, whose secondary output leads 88 and 90 are connected across the insulation system to be tested 92. The limitations of this system lie in the requirement that both the mains 80 and 82 and the variable voltage device 84 must be capable of furnishing the total energy required for the test. Since test energy is proportional to the square of test voltage, the previously discussed trend toward increased operating voltage caused energy requirements to outstrip the ability to economically produce variable voltage devices.

In order to overcome this obstacle a series resonant system had been developed by Ferranti and widely employed about a quarter century ago. A variation of this

method was described by Peschel in U.S. Pat. No. 3,515,986. A circuit for performing this method is illustrated in FIG. 6a. Alternating current energy is introduced, via mains 94 and 96 to variable voltage device 98. A variable inductance 100 is connected in series with the test object 102 and the magnitude of inductive reactance is adjusted until it equals the capacitive reactance of the test object 102. The Ferranti technique accomplishes multiplication of the input voltage, E, as shown in the phasor diagram FIG. 6b. By this means, the energy capability of the mains and the variable voltage device need be only large enough to supply the losses of the circuit, predominantly centered in the variable inductor. A quality factor Q, may be defined as the ratio of reactive energy to power, or

$$Q = \frac{E_r I}{EI} = \frac{E_r}{E}$$

The Ferranti system has several disadvantages. First, in order to generate any output voltage greater than E, it is necessary that the system be loaded with some value of capacitance that falls within the range of the variable inductor. Second, the magnitude of test voltage, E_r , is dependent upon the magnitude of both Q and E. If Q is made large in order to obtain a favorable ratio of output to input energy, small instabilities in the setting of the variable inductor can result in dramatic changes in the value of E_r .

A technique in accordance with the present invention which may be designated as parallel resonance is illustrated in FIG. 7. In this method, the variable inductor 104, is connected in parallel with the test object 106, via leads 108 and 110, in parallel with the variable voltage divider 116. The voltage supply through mains 112 and 114 to the variable voltage divider 116 remains essentially the same. It will be seen that, when the variable inductor 104 is adjusted so that its reactance equals the capacitive reactance of the test object 106, the only current that need be supplied is that current, I, which is in phase with the supply voltage, E, as required to supply the losses, largely centered in the variable inductor. It will be noted that the test voltage is identical to the voltage applied to the combination and is therefore independent of tuning of the reactor, 104. Instabilities in tuning of the variable inductor will result in changes only in the amount of current, I, which is drawn from the mains and will leave the magnitude of test voltage unchanged. When the parallel inductive reactance and capacitance reactance are equal, the current is minimum. Therefore, setting of the variable inductor may be monitored by observing supply current I as the inductance is varied and leaving the setting at that position which produces minimum supply current out of the variable voltage supply.

In addition to the combination shown in FIG. 7, it is possible to provide combinations of windings and taps so as to permit various configurations of the parallel resonant technique. In FIG. 8, which identified like parts to those employed in FIG. 7 with the same number designator plus the addition of primes, the variable inductor 104' is tapped at 118 and the inductor is operated as an autotransformer. By this means, a fixed ratio, N, of output to input voltage is established depending upon the ratio of the total number of turns in the reactor to the number of turns between tap 118 and lead 110'; thus, test voltage is still independent of Q. This

configuration permits the use of a much lower mains voltage than is required for the configuration shown in FIG. 7. The procedure in setting the inductance again involves monitoring supply current I until the resonance produces a minimum I.

Another technique for multiplication of input voltage exclusive of tuning is shown in FIG. 9 wherein input voltages from mains 120 and 122 is supplied through by variable voltage device 124. This circuit employs a conventional transformer 126, capable of delivering the full energy required for the test. Just as in the prior art of FIG. 5, such a transformer accomplishes voltage multiplication by its turn ratio, N, the ratio of the number of turns on the secondary, or output, winding to the number of turns on the primary, or input winding. When the variable inductor 128 is connected across the input winding, as shown in FIG. 9, and adjusted to the correct value, the variable voltage device need only supply the losses of the combination, largely centered in the variable inductor 128, and high voltage transformer 126. This combination has the advantage of permitting a low mains voltage and a test voltage which is independent of the value of Q or the setting of the variable inductor 128. In addition, by virtue of the insulation between windings of the high voltage test transformer, it permits complete electrical isolation of the power input circuit and the high voltage test circuit.

FIG. 10 shows still another device in which variable inductor 132 is a transformer. An independent low voltage winding is employed in the variable inductor in such a fashion that the windings are electrically insulated but share a common magnetic core. For example winding 134 and 140 may be separate windings of a transformer. In this case the primary 134, or low voltage, winding and the variable voltage device 136 need only be capable of handling the current required for supplying the losses in the circuit. The secondary winding 140 of the variable reactor, 132 must be able to withstand the high voltage experienced by the capacitance load 138. The technique for setting the variable inductive reactor again involves adjustment while observing the supply current and stopping at the minimum current.

FIG. 11 diagrammatically shows the action of crank 20b upon linkage 24b as the crank is driven in clockwise rotation from the position as viewed in FIG. 1. The direction of rotation is illustrated by a circular pattern through a portion of which pins 22b and 22a respectively move. While the upper position of the movable support member and the core member 12b, with the core in its position of maximum withdrawal, have been shown in phantom in FIG. 1, the corresponding position of the actuators has not been shown lest it cause confusion. However, in FIG. 2 the position of the actuators for maximum retraction of the core from the coils is shown in dashed lines so that their relative positions may be compared. FIG. 11 then gives a schematic view corresponding to that of FIG. 1 showing several of the successive positions of pin 22b and the arcuate pattern the pin follows between extreme positions of the actuator. Incidentally, when the gap is a minimum, one limit of the structure is obtained. Since the core tends to pull together by magnetic force, including residual magnetic forces, as well as gravity, there is no problem about providing a stop or limit for this end of the motion. Motion in the other direction, however, must be stopped or limited, and this may be done by providing

limit switches which stop the motor means when the ultimate position has been obtained.

It is a requirement of the design to provide a great mechanical advantage in the mechanism used to pull the core members apart because great forces are involved in movement and in holding the core in any selected position. The gear boxes 30a and 30b, for example, may employ worm gears or other effectively "one way" mechanisms permitting easy drive but resisting gravity and other forces tending to move the core without drive. The structure of the present invention provides the great advantage of providing maximum force with minimum movement when the cores are first moved apart and thereafter moving toward a situation in which the force provided is less and the distance moved is greater. However, it will be observed in FIG. 12 that the gap motion in terms of time can be made almost uniform throughout a large portion of its travel using the structure of the present invention. This is true even though the velocity at which the gap is varied is initially very low and accelerates to a higher level, finally dropping off as 100 percent of the movement is achieved, as shown by the dashed curve marked gap velocity in FIG. 12. These curves are intended to be typical of the conditions existing in structures of the type illustrated.

While but a single embodiment of the variable inductive reactor of the present invention has been illustrated, it will be clear to those skilled in the art that additional embodiments will be possible within the scope of claims. The structure involved is a very specific type of structure designed to overcome problems encountered in the prior art. Nevertheless, modifications within the teaching of the present invention are possible and intended to be within the scope and the spirit of the claims which are appended hereto.

Furthermore, the method of the present invention is applicable to structures other than these claimed herein, although such structures are preferred. In accordance with the method of the present invention any suitable variable inductive reactor may be employed provided that it is capable of being suitably adjusted and able to be set in a selected adjustment and retain that adjustment for a test period.

We claim:

1. A variable inductive reactor comprising, a pair of laminated iron core members, each having at least a portion of generally U-shape, the legs of which are opposed and together define a magnetic circuit, said core members being separable to provide air gaps in the magnetic circuit between the opposed legs, a frame supporting one of said core members, coil means supported on said frame and positioned to

surround at least one of said opposed legs at the air gap, thereby to provide a variable inductive reactor,

movable support means for supporting the other of said core members having a slidable cooperative relationship with said frame whereby movement is restricted to a predetermined fixed and repetitive path producing an opening of the air gap in one direction and a closing of the air gap in the other direction of movement,

actuator means acting between the frame and the support means to produce such movement and including a pair of symmetrically arranged crank elements connected to articulated linkages, and

drive means to move the cranks in synchronism between predetermined positions providing preselected alternative core positions.

2. The variable inductive reactor of claim 1 in which the frame supports one of said core members so that its legs extend generally in the direction of motion and at least one electrical winding is provided to surround each of said legs, said windings together constituting the coil means, the movable support means is slidably movable along a linear path relative to the frame by which movement parallel air gaps between the legs of the core members are opened or closed and the cranks turn in opposite directions about parallel axes.

3. The variable inductive reactor of claim 2 in which the drive means is a motor means operating through similar coupling means to drive each crank.

4. The variable inductive reactor of claim 3 in which the common motor means has its shaft parallel to the shafts of the cranks and supplies drive through at least two similar gear boxes.

5. The variable inductive reactor of claim 4 in which the common motor means is located between the cranks and has a dual takeoff arranged to drive sprocket wheels engaging parallel chain drives which, in turn, drive sprocket wheels on similar gear boxes connecting the drive shafts of the respective cranks.

6. The variable inductive reactor of claim 2 in which the coil means includes at least two windings providing a transformer action due to magnetic coupling through said core means.

7. The variable inductive reactor of claim 6 in which each of the two windings surrounds separate legs of the core.

8. The variable inductive reactor of claim 2 in which the windings around the respective legs are connected in series with one another.

9. The variable inductive reactor of claim 8 in which an autotransformer connection is made into the series windings.

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